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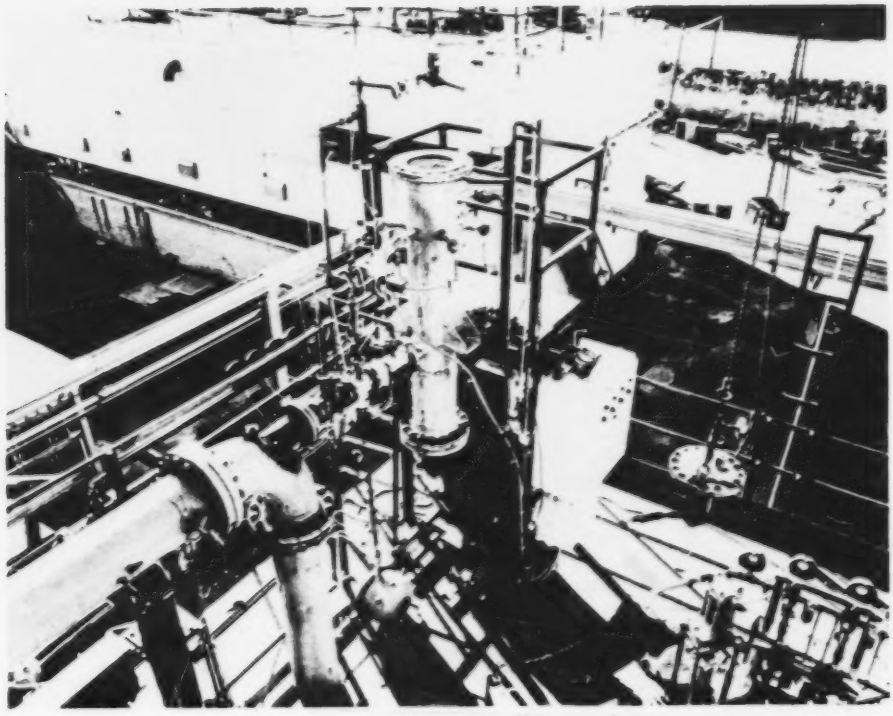

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Particulate Control Highlights:
Research at High Temperature/Pressure

by

Dennis C. Drehmel and James H. Abbott

EPA, Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711

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Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

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ABSTRACT

Although particulate control equipment can be demonstrated to have high collection efficiency in some applications, extreme conditions of temperature, pressure, or both pose special problems. Aqueous scrubbers and filters using organic media have obvious temperature limitations. Electrostatic precipitators (ESPs) are commonly used on the hot side of the air preheater in power plants but performance at high temperatures such as 600°C is yet to be demonstrated. The need for control at extreme conditions arises in metallurgical operations and advanced energy processes. Consequently, EPA has conducted a program of research and development for control of particulates at high temperature and pressure.

Among the control devices given consideration in the program were cyclones, granular bed filters, dry scrubbers, molten scrubbers, ESPs, ceramic bag filters, and other ceramic filters not of a bag configuration. Advantages and disadvantages of these devices involve parameters such as simplicity of operation, materials problems, inability to collect submicron particles, difficulty in regenerating the collection media, and those related to cost, including size and pressure drop. Since these advantages and disadvantages can be weighed differently according to the needs of a specific application, it is not possible to give universal conclusions. However, if the most important consideration is control of submicron particles, ceramic filters are foremost.

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Introduction

The Environmental Protection Agency (EPA) and its predecessor organizations have actively investigated improvements in airborne particulate control for 10 years. Five years ago it was recognized that extending the operating range of conventional devices to high temperature and high pressure (HTP) would be necessary to provide abatement for a variety of industrial and advanced energy sources such as fluidized bed combustors and coal gasifiers. In addition it was recognized that stationary fuel combustion was the largest source category for particulate emissions.[1] Consequently, EPA focused its programs on fuel combustion and especially on power production and energy conversion.

The objective of these programs was to demonstrate control technology to meet environmental standards concerning the ambient concentration of particles and the emission rate of particles from new sources. The current standard for power conversions states that new source shall not emit more than 0.1 pounds of particulate matter for every million Btu's of thermal energy released (43 ng/J). It is expected that this standard will be lowered and future ambient air standards may apply to particles less than 15 μm.

To meet this objective for HTP processes, EPA developed the program illustrated in Figure 1. Particulate control at high temperature and pressure was thought to be possible with cyclones, ceramic filters, granular bed filters, non-aqueous scrubbers, and specially designed electrostatic precipitators. However, models predicted that cyclones would be less than 50 percent efficient below 1 μm and data indicated poor efficiency even at 2.5 μm.[2] Since collection of fine particles was a pending subobjective to meet EPA standards, and cyclones demonstrated low potential for fine particle collection, no development of cyclones was planned. Development of the other approaches was planned as indicated in Figure 1. The results of the progress along each path of Figure 1 are the subject of this report. Results of a field test of high temperature and pressure cyclones are also included for comparison.

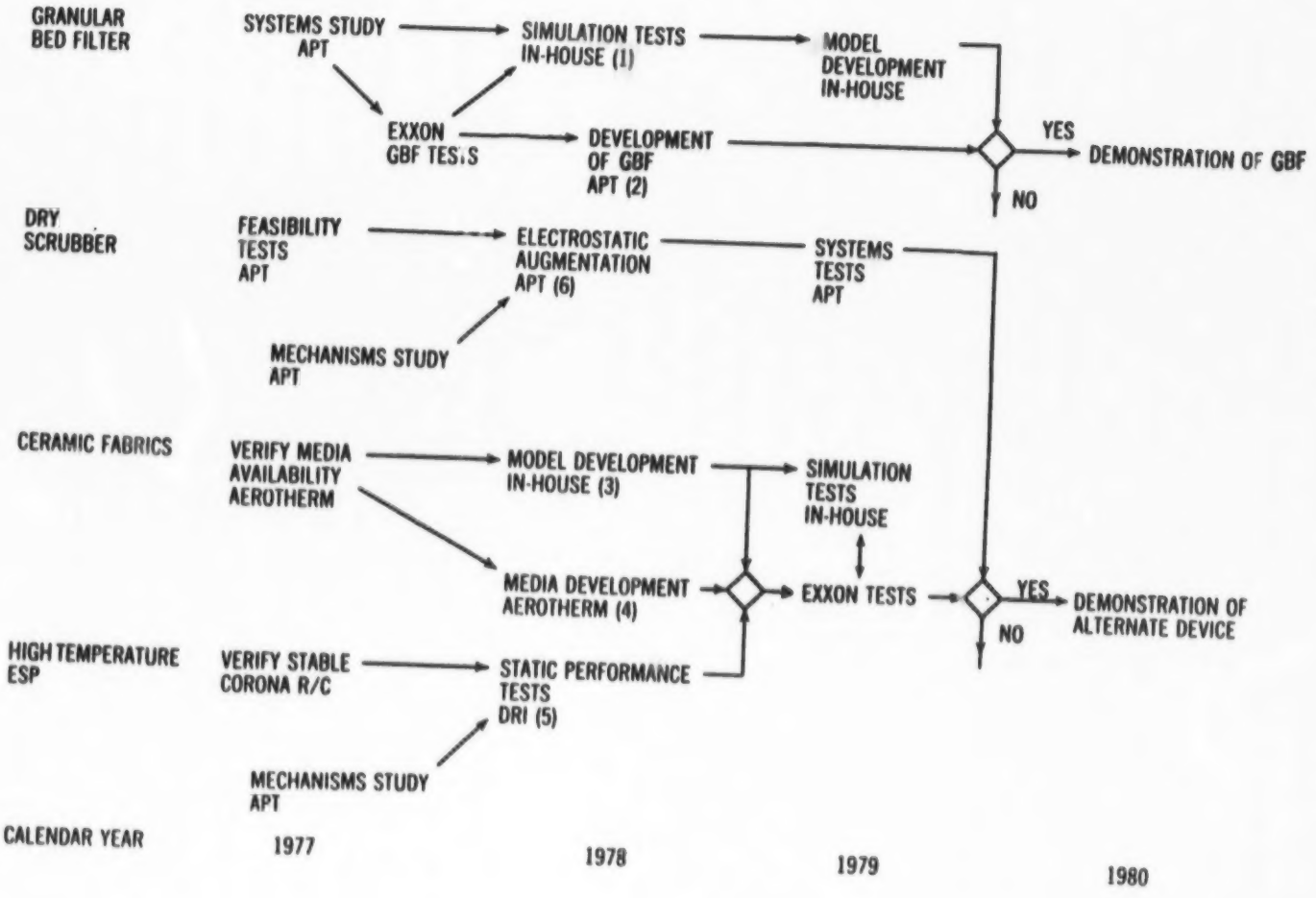


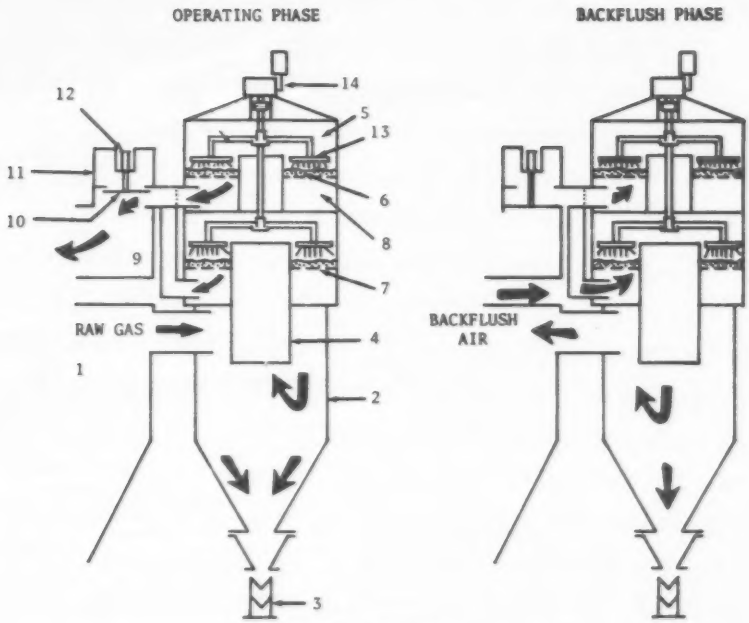
Figure 1. High temperature/pressure control

Granular Bed Filters (GBFs) and Dry Scrubbers

Granular bed filters and dry scrubbers may be defined as any collection system comprised of stationary or moving discrete, relatively closely packed granules as the collection medium. With respect to motion of the granules, granular bed filters may be classified as moving or fixed bed filters. Dry scrubbers may be very similar to moving bed filters except that the gas stream may be accelerated before contacting the granules in order to maximize collection from impaction.

To evaluate granular bed filters and dry scrubbers, two contracts with Air Pollution Technology were initiated in 1976 (68-02-2164 in August and 68-02-2183 in September). The purpose of these contracts was to assess the application of the APT dry scrubber and granular bed filters, as made by Rexnord (Figure 2), Ducon (Figures 3 and 4), and Combustion Power Co. (Figures 5 and 6), to the problem of particulate control at high temperature and pressure. The results of these contracts may be illustrated by comparing the APT, Combustion Power Company (CPC), and Ducon control devices. These three devices give a range of design features available for collection of particulate on hard granules (see Table 1). At one end of the spectrum are fixed granular bed filters which rely on collection throughout the bed material until a layer or cake is formed. The cake provides greater filtration efficiencies especially for submicron particles. Optimizing the performance of the fixed granular bed filter requires a cleaning system which preserves some of the cake while preventing unacceptably high pressure drops. Moreover, it is essential that the cleaning systems not allow particulate to work its way through the bed either by insufficient cleaning or by motion of the granules.

At the other end of the spectrum is the dry scrubber which relies only on impaction for collection; a cake is never formed. In this case, the gas velocity is high to optimize impaction. Collection of submicron particles may be augmented by charging particles and granules with different signs. In 1978, EPA began work with APT, Inc. (Contract 68-02-3102) to verify the benefits of using electrostatics in dry scrubbers. Cold flow experiments confirm that penetration of submicron particles can be reduced by a factor of 4. Hot flow experiments will be completed in 1980.



1. INLET CHAMBER
2. PRIMARY COLLECTOR (CYCLONE)
3. DOUBLE TIPPING GATE (DUST DISCHARGE)
4. VORTEX TUBE
5. FILTER CHAMBER
6. GRAVEL BED
7. SCREEN SUPPORT FOR BED
8. CLEAN GAS COLLECTION CHAMBER
9. EXHAUST PORT
10. BACKWASH CONTROL VALVE
11. BACKWASH AIR INLET
12. VALVE CYLINDER
13. STIRRING RAKE
14. STIRRING RAKE MOTOR/REDUCERS

Figure 2. Rexnord filter.

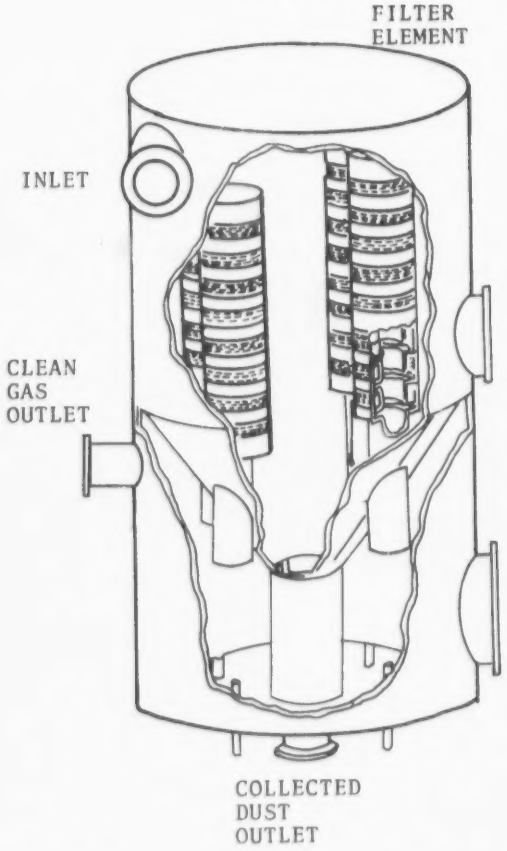


Figure 3. Ducon filter.

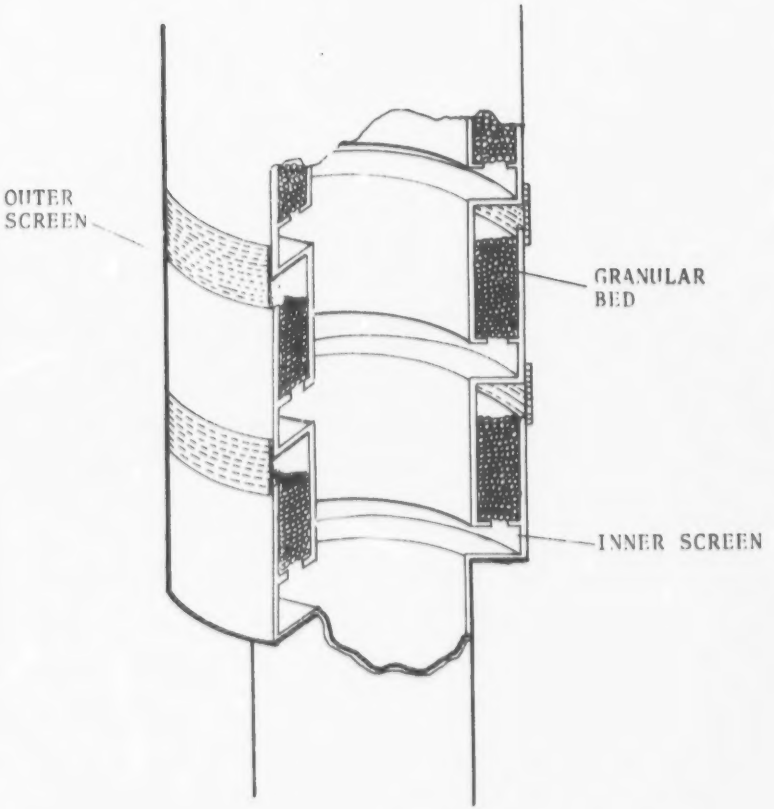


Figure 4. Detail of Ducon filter using screens.

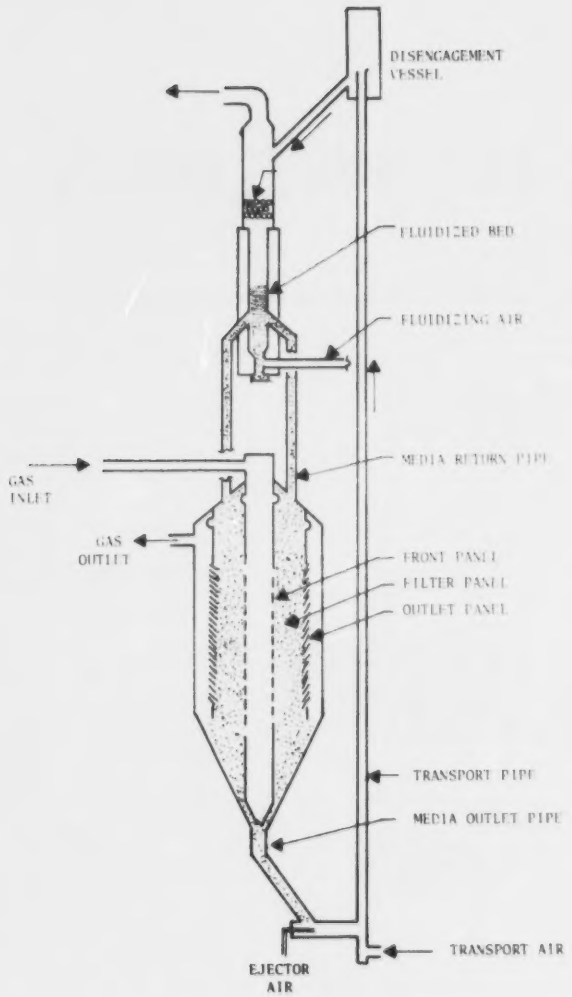


Figure 5. Combustion Power filter.

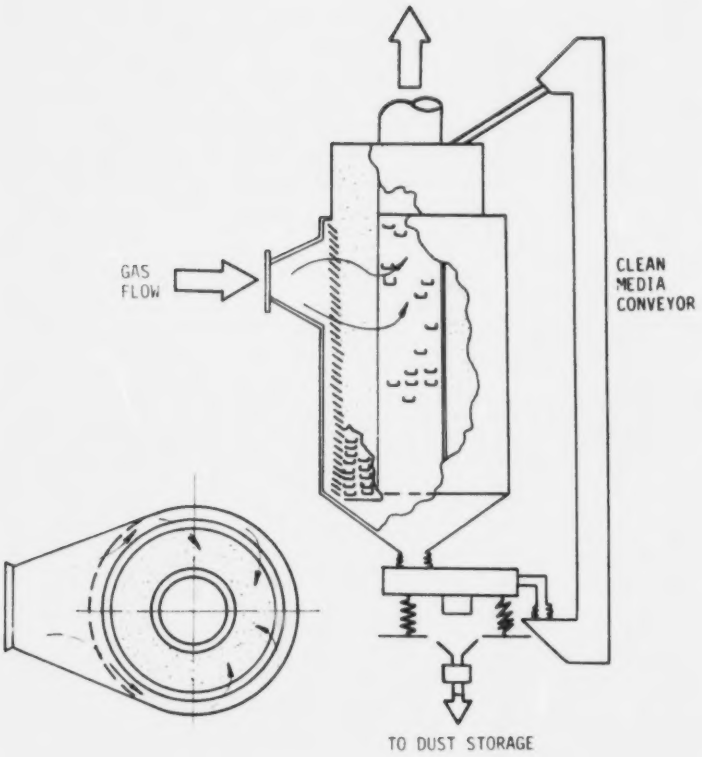


Figure 6. Detail of collecting bed in CPC filter.

Table 1. SUMMARY OF PERFORMANCE INFORMATION

	Moving Granular Bed Filter (CPC)	Dry Scrubber (APT)	Fixed Granular Bed Filter (Ducon)
Superficial gas velocity, cm/s	20-80	3,000-6,000	45
Pressure drop, kPa	1.2-5.7	2-7	8 (from prediction)
Bed depth, cm	20-40	NA	3.8
Granule diameter, cm	0.08-0.2	0.01	0.04
Efficiency at 1 μm, %	78	96	82
Efficiency at 6 μm, %	93	99	96

In the middle of the spectrum is the moving granular bed filter in which the granules move slowly enough to form a bed which acts like a filter. This device works partially by impaction and partially by filtration but cannot be optimized for either since the gas velocities are low and the bed is removed before a cake is formed. However, some designs using intermittently moving granular beds do establish and preserve the cake for better filtration.

The information in Table 1 is a quick comparison of the points in the spectrum discussed above. Pressure drops for all three devices tend to be the same. The APT dry scrubber has a very high gas velocity and no bed. The CPC moving granular bed filter has a low gas velocity and a thick bed. The Ducon filter has a low gas velocity and a thin bed. The thick bed is used with the CPC moving bed filter to ensure good filtration in the absence of cake filtration or high gas velocity for impaction collection. In the case of these data the APT dry scrubber gave the best performance. However, development of all these devices continues and it would be premature to conclude that efficiencies will not be improved. Both the APT and CPC devices can be augmented with electrostatic effects such as imposing a field or charging the particles, charging the granules, or both. Further development of the Ducon device will necessitate improved cleaning to avoid problems noted in tests at the Exxon Miniplant.[3] Tests at Exxon were terminated after a series of difficulties including plugging and rapid loss of acceptable filtration efficiency. Because of these results, further development of GBFs was ended early and points 1 and 2 on Figure 1 were never reached.

Ceramic Filters

Two types of ceramic filters were investigated: 1) flat rigid filters, and 2) cylindrical bag filters. The first was made the subject of Westinghouse Contract 68-02-1887 and the second, Aerotherm Contract 68-02-2169. A number of rigid ceramic filters were tested including cubes comprised of thin filtering barriers separated by alternating layers of corrugations. The advantage of the filtering cube is that it has large surface area to volume ratios and has added strength to withstand mechanical and thermal stress. Using a limestone test dust dust

with a mass median diameter of 1.4 μm, the collection efficiency averaged 96.4 percent in experiments at temperatures from 360 to 815°C.[4] The disadvantage of the filtering cube is that the void spaces are small and could rapidly fill and plug with collected material. This would be especially true with tarry particles from coal gasification or sticky particles as encountered at the Exxon fluid bed combustor Miniplant.

Ceramic bag filters were investigated with three basic media types: 1) woven ceramics, 2) ceramic papers, and 3) ceramic felts. Tests with 0.3 μm particles showed that woven ceramics had low collection efficiencies, always below 50 percent, and ceramic papers and felts had high collection efficiencies, up to 99.5 percent.[5] Another advantage of ceramic felts was a loose flexible structure which would provide the durability needed to withstand a miniumum lifetime of cleaning, typically requiring several million cleaning cycles. For these reasons, it was decided to continue the program with development of the ceramic felt media (point 4 in Figure 1) and to arrange tests at the Exxon fluid bed combustor Miniplant. Under contract 68-02-2611, Aerotherm performed extended tests of Saffil* alumina, a type of ceramic felt, and demonstrated that this media (as developed by Aerotherm) could be cleaned up to 50,000 times at 815°C and 9 atm without damage to the ceramic bag filter.

Tests at the Exxon Miniplant (see Figures 7 and 8) were run under varying gas velocities through the bag and during combustion of two different coal types in the fluid bed combustor. It was found that coal type had little effect on filter performance. When superficial gas velocity was increased from 4 to 10 cm/s there was a slight decrease in efficiency from 99.4 to 98.6 percent. No problems with bag cleaning were encountered and residual pressure drops were always below 5 kPa (20 in. H_2O). As shown by a vacuumed strip, filtration was on the outside of the bag with no penetration of fine particles (see Figure 9). In comparison to filters described in Table 1, this pressure drop is in the same range, superficial gas velocities are lower, and efficiencies are higher. The central remaining question for ceramic felt bag filters is the upper limit on bag lifetime. Although these bags are relatively inexpensive, trouble-free operation between scheduled outages would be

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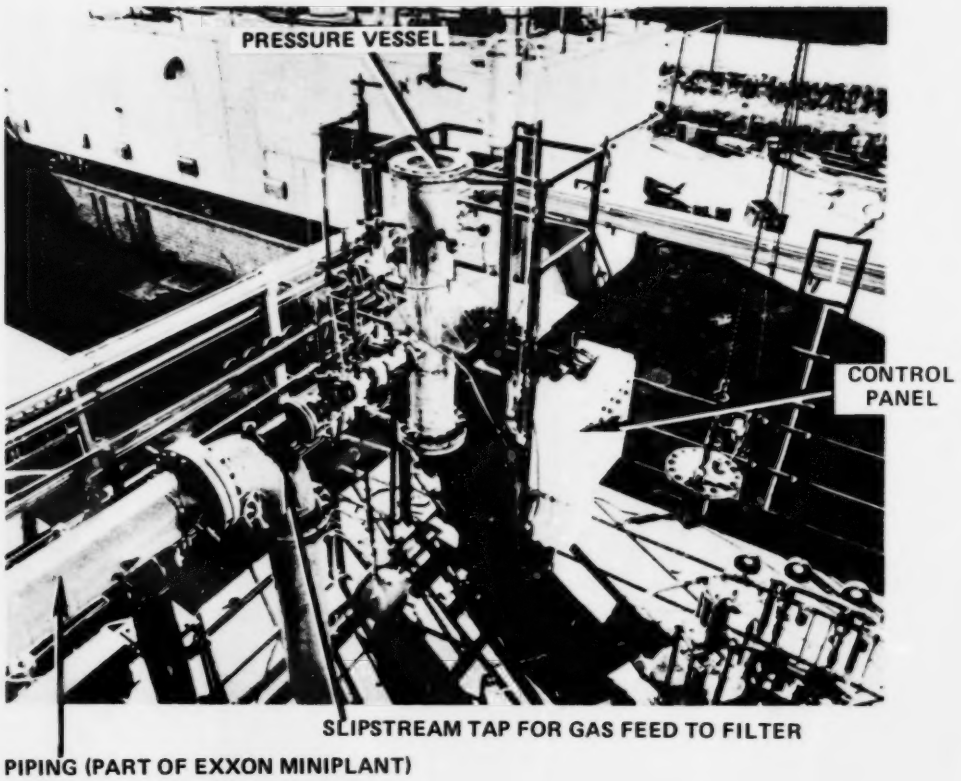

Figure 7. Ceramic bag test module at Exxon.

Figure 8. Detail of Saffil alumina ceramic bag.

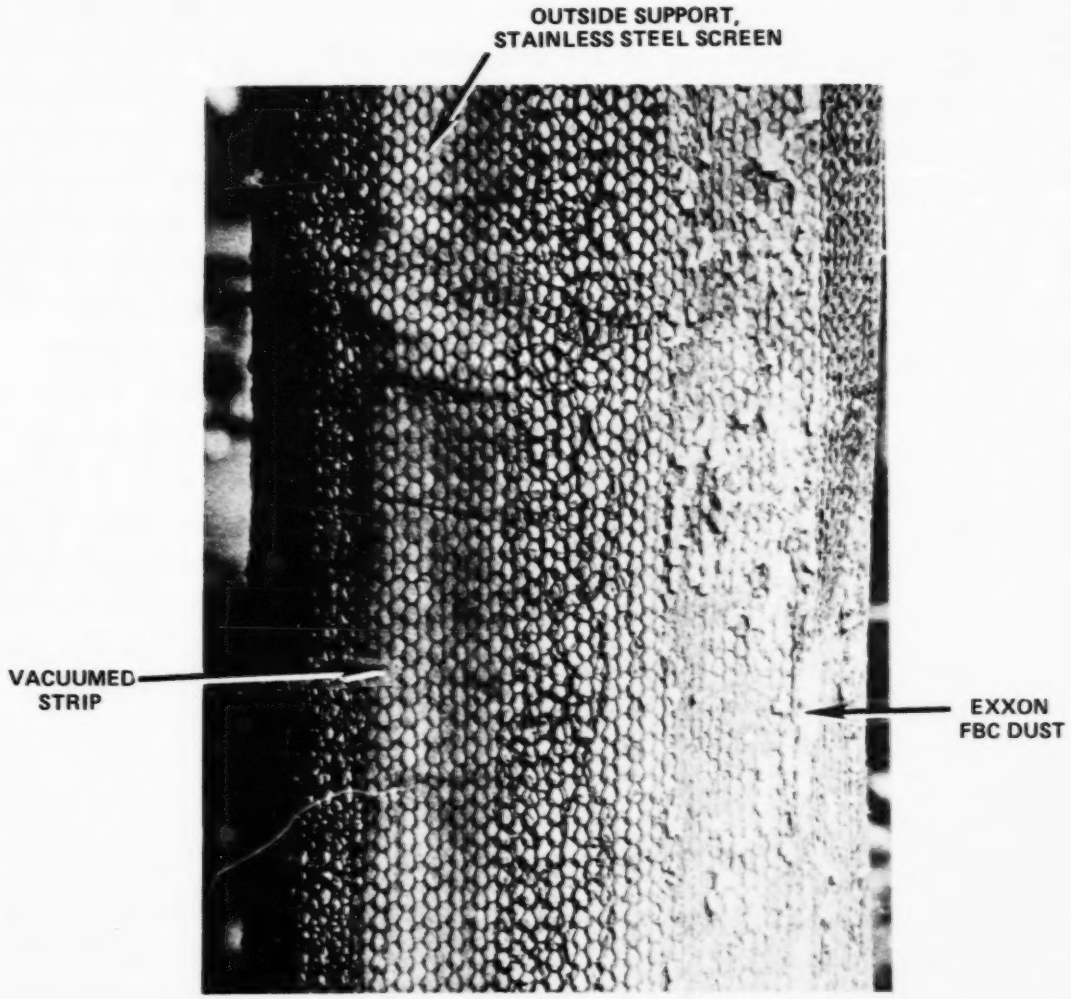

Figure 9. Close-up of bag showing vacuumed strip.

necessary. Consequently, demonstration of long term bag lifetime is still required.

Electrostatic Precipitators

Under EPA contract 68-02-2104, Research Cottrell was asked to verify the operability of electrostatic precipitators (ESPs) at high temperature and pressure. The objectives of this work were to define the temperature and pressure regions in which stable ESP operation is possible and to determine the suitability of ESPs for particulate cleanup on advanced energy conversion processes. ESPs work by producing ions which charge the particles and cause the particles to migrate to the collection plate under the influence of an electric field. The ions are produced by corona discharge which will not be stable if sparkover conditions are reached. Research Cottrell did verify that stable corona was possible over the entire range of temperature and pressure combinations of advanced energy conversion processes. Research Cottrell also found that performance improved with increased temperature and pressure. This implies that satisfactory collection efficiencies could be attained. As an independent assessment, work was begun at Denver Research Institute (grant 805939) to test an operating ESP at high temperature and pressure (refer to point 5 on Figure 1). Results from this project will be available in 1980.

Cyclones

Although no development of cyclones was undertaken, cyclones are of interest because of their simplicity. A field test of the testing cyclone at the Exxon Miniplant shows that in this case significant collection below 1 μm is possible. With a pressure drop of 3.7 kPa (15 in. H_2O), the collection efficiency at 1 μm was 80 percent; at 0.8 μm, 70 percent; and at 0.7 μm, 50 percent. Although these results are not unreasonable considering the pressure drop,[6] they do not fit available cyclone models which underpredict these efficiencies.[7] In light of the extremely sticky nature of the particles at the Exxon Miniplant, it is possible that the apparent collection of submicron particles is due to agglomeration into larger size regions. Further

consideration of cyclones will have to be on an application by application basis.

Summary

A spectrum of granular collecting devices has been discussed in terms of three examples under development. Advantages of these differing approaches are:

APT Dry Scrubber

High collection efficiency possible from impaction and electrostatic attraction. Collecting granules are removed from the system for easy cleaning.

Ducon Fixed Bed Filter

High collection efficiency possible from cake filtration. Low attrition rates of bed material. Minimum energy requirement because of low heat loss and no bed recirculation power.

CPC Moving Granular Bed Filter

Collecting granules are removed from the system for easy cleaning. Electrostatic augmentation may provide high collection efficiencies.

In choosing between these alternatives, important considerations include cost, the adhesiveness of the particulate, and the importance of energy conservation. For example, if the particulate is sticky, a system which removes granules for easy cleaning will be necessary. On the other hand, if a fixed bed filter can be cleaned and removal of granules implies a high energy loss, cost considerations may favor the fixed bed filter.

A number of investigators have shown that high collection efficiencies are possible with ceramic filtration at high temperature (greater than 800°C) and/or high pressure (greater than 900 kPa). The recent work has tested both ceramic bags and rigid ceramic filters. Advantages of these different approaches are:

Ceramic Bag

High collection efficiency. Easy to clean. Resists failure because of thermal shock.

Rigid Ceramic Filter

High collection efficiency. Compact. Resists failure because of high pressure drop.

The endurance of both media is unknown. If the rigid ceramic filter can be used without clogging or thermal shock, it could be maintained in service for many years. However, ceramic bags are expected to have a limited life because of the less durable nature of the bag structure. Tests to date indicate that ceramic bags will easily survive up to 50,000 cleaning pulses or the equivalent of 1 year's light service.

Other devices considered are electrostatic precipitators and cyclones. Advantages of these are:

Electrostatic Precipitator

Very small pressure drop. High collection efficiency possible.

Cyclone

Simple. Available.

However, high temperature and pressure electrostatic precipitators need further development before application. Cyclones may be efficient in some cases, but generally low efficiency should be expected for fine particles.

A concluding comparison of all devices is given in Table 2. Selection of a device will depend primarily on the efficiency required and how soon the device is needed. Approaches such as the APT scrubber and the ceramic felt bag are the next to become available and offer higher efficiencies than commercial filters and cyclones. However, in comparison to filters, ceramic bags have low superficial velocities which may lead to large capital intensive control units. Furthermore the APT dry scrubber still needs testing at the pilot scale.

Table 2. COMPARISON OF HIGH TEMPERATURE/PRESSURE CONTROL DEVICES

Device	Superficial Velocity c/s	Pressure Drop kPa	Efficiency at 1 μm %	General Status
APT Dry Scrubber	3000-6000	2-7	96	bench
CPC Filter	20-80	1-6	78	commercial
Ducon Filter	45	8	82	commercial
Ceramic Bag	4-10	5	99	pilot
Electrostatic Precipitator	100-200	0.2	NA	bench
Exxon Cyclone	NA	4	80	commercial

References

1. Vandegrift, A. E. et al., "Particulate Pollutant Systems Study," EPA No. APTD 0743, NTIS No. PB 203-128, May 1971.

2. Ciliberti, D. F. and B. W. Lancaster, "Performance of Rotary Flow Cyclones," AIChE J 22:2, p. 394, March 1976.

3. Hoke, R. C. et al. "Miniplant Studies of Pressured Fluidized-Bed Coal Combustion: Third Annual Report". EPA-600/7-78-069, NTIS No. PB 284-534, April 1978.

4. Drehmel, D. C. and D. F. Ciliberti, Paper #77-32.4, APCA Annual Meeting, Toronto, Canada, June 1977.

5. Drehmel, D. C. and M. S. Shackleton, Paper #17, Third Symposium on Fabric Filters for Particulate Control, Tucson, Arizona, December 1977.

6. Drehmel, D. C., Fine Particle Control Technology, JAPCA 27:138, 1977.

7. Parker, R. D., Private communication to D. C. Drehmel, 1979.11

BIBLIOGRAPHY

1. Calvert, S. et al., "Effects of Temperature and Pressure on Particle Collection Mechanisms: Theoretical Review," EPA-600/7-77-002, U.S. E.P.A., Research Triangle Park, N. C., 96 pp., NTIS PB 264-203/AS, January 1977.

2. Kennedy, R.A. et al., "EPA and ERDA High-Temperature/High-Pressure Particulate Control Programs," EPA-600/7-77-013, U.S. E.P.A., Research Triangle Park, N. C., 60 pp., NTIS PB 266-231/AS, February 1977.

3. Poe, G. G. et al., "Evaluation of Molten Scrubbing for Fine Particle Control," EPA-600/2-77-067, U.S. E.P.A., Research Triangle Park, N.C., 36 pp., NTIS PB 266-092/AS, March 1977.

4. Poe, G. G. et al., "Evaluation of Ceramic Filters for High-Temperature/High-Pressure Fine Particulate Control," EPA-600/2-77-056, U.S. E.P.A., Research Triangle Park, N. C., 55 pp., NTIS PB 266-093/AS, February 1977.

5. Parker, R. and S. Calvert, "High-Temperature and High-Pressure Particulate Control Requirements," EPA-600/7-77-071, U.S. E.P.A., Research Triangle Park, N. C., 123 pp., NTIS PB 271-699/AS, July 1977.

6. Ciliberti, D.F., "High Temperature Particulate Control with Ceramic Filters," EPA-600/2-77-207, U.S. E.P.A., Research Triangle Park, N. C., 172 pp., NTIS PB 274-485/AS, October 1977.

7. Bush, I. R. et al., "Development of a High-Temperature/High-Pressure Electrostatic Precipitator," EPA-600/7-77-132, U.S. E.P.A., Research Triangle Park, N. C., 85 pp., NTIS PB 276-626/AS, November 1977.

8. "EPA/DOE Symposium on High-Temperature, High-Pressure Particulate Control," EPA-600/9-78-004, 633 pp., NTIS No. CONF-770970, March 1978.

9. Shackleton, M. A., "High-Temperature, High-Pressure Particulate Control with Ceramic Bag Filters," EPA-600/7-78-194, U.S. E.P.A., Research Triangle Park, N. C., 93 pp., NTIS PB 290-104/AS, October 1978.

10. Parker, R. and S. Calvert, "Alternatives for High-Temperature/High-Pressure Particulate Control," EPA-600/7-79-019, U.S. E.P.A., Research Triangle Park, N. C., 135 pp., NTIS PB 292-687/AS, January 1979.

11. Yung, S. et al., "Evaluation of Granular Bed Filters for High-Temperature/High-Pressure Particulate Control," EPA-600/7-79-020, U.S. E.P.A., Research Triangle Park, N. C., 240 pp. NTIS PB 299-195/AS, January 1979.

12. Shackleton, M. A., "Extended Tests of Saffil Alumina Filter Media," EPA-600/7-79-112, U.S. E.P.A., Research Triangle Park, N. C., 30 pp., NTIS PB 297-567/AS, May 1979.

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16. ABSTRACT The report gives highlights of EPA high-temperature and high-pressure programs aimed at demonstrating control technology to meet environmental standards for the ambient concentration of particles and the emission rate of particles from new sources. Among the control devices considered in the EPA programs were cyclones, granular bed filters, dry scrubbers, molten scrubbers, electrostatic precipitators (ESPs), ceramic bag filters, and other (non-bag) ceramic filters. Advantages and disadvantages of the devices involve parameters such as simplicity of operation, materials problems, inability to collect submicron particles, difficulty in regenerating the collection media, and those related to cost, including size and pressure drop. Since these advantages and disadvantages can be weighed differently, according to the needs of a specific application, it is not possible to give universal conclusions. However, if the most important consideration is control of submicron particles, ceramic filters are foremost. Although particulate control equipment can be demonstrated to have high collection efficiency in some applications, extreme conditions of temperature, pressure, or both pose special problems. The need for control at extreme condition arises in metallurgical operations and advanced energy processes.

17. KEY WORDS AND DOCUMENT ANALYSIS

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